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Soil Losses from Roadbeds and Cut and Fill Slopes in the Southern Appalachian Mountains

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ABSTRACT. Soil losses were measured on the cut, fill, and roadbed surfaces of a forest road at Coweeta Hydrologic Laboratory. Before grass was planted or gravel spread, roadbed surfaces had the least loss per unit area and loss was primarily waterborne fine particles. A large part of the soil loss from fill slopes was due to slippage of wet soils in early spring. Surface erosion of fills was negligible because storm water from the roadbed was not spilled across loose soil. The cut slopes eroded most, principally because soils were loosened by diurnal cycles of freezing and thawing in winter. This study shows that inclined surfaces of cut and fill slopes are potential sources of large soil loss but these losses can be mitigated by early establishment of grass cover and by design features to control storm water. Soil loss from roadbeds was greatly reduced by gravel surfacing.[1]

[1] The Southern Region of the Forest Service and national forests in North Carolina contributed to this study by constructing the two test sites and providing surveys and soil test data. Storm and erosion data collected during this study were shared with the Engineering Research Center, Colorado State University. Their contract to adapt and demonstrate an erosion prediction model for southeastern conditions has not been completed.

Roads are often the major source of soil erosion from forested lands (Patric 1976). The roadway, or area of exposed soil of a newly constructed road, consists of three distinct surfaces with different characteristics that affect their erodibility. These surfaces are the cut slope, the roadbed, and the fill slope. Measurements were made on an access road to a Forest Service timber sale to increase the information available on comparative erosion rates from the cut, bed, and fill of forest roadways. Generally, soil loss is greatest during and immediately after construction. In this study, the time between construction and seeding grass and spreading gravel was longer than is recommended so that soil losses from bare slopes and roadbeds could be quantified during several seasons and for different traffic intensities. Although measurements created some artificial conditions, study results are informative and useful to the land manager and engineer because they point out major causes, locations, and seasons of soil loss and demonstrate the value of grass and gravel for reducing erosion.

METHODS

The road is at 3,560-ft. elevation, traversing on the contour a 35% southfacing slope at the Coweeta Hydrologic Laboratory in the southern Appalachian Mountains of western North Carolina. Mean annual rainfall at the site is 73.8 in. distributed throughout all seasons. The climate is moderate with mean monthly air temperatures ranging from 72°F in summer months to 25°F in January. Some precipitation falls as snow and usually melts within a few days. The soil series is Chandler, a micaceous, deep sandy loam which has a relatively low hard rock content. The engineering classification for the nonplastic soil material is A-2-4 under the American Association of State Highway and Transportation Officials system and SM for the American Society for Testing and Materials system. This Typic Dystrochept soil is dominant on the drier upper slopes at Coweeta and common on similar sites throughout the southern Appalachians. An oak-hickory forest with dense understory is the typical cover. Undisturbed soils, protected by vegetation and a litter layer, absorb all precipitation, and surface runoff exists only on disturbed sites or in permanent and intermittent stream channels.

Two sections of road were reconstructed in 1976 to have outsloped, 22-ft.-wide roadbeds drained by broad-based dips without inside ditches. This forest road design was developed at Coweeta (Hewlett and Douglass 1968) and is implemented in many types of terrain (Cook and Hewlett 1979). Each test site was defined as a broad-based dip plus the 190-ft. or less length of roadbed drained by that dip. Size and angle of cut and fill slopes were similar between the two sites. Cut slopes ranged from ¾:1 to 1:1 and fills from 1:1 to 1¼:1. The toe of each fill terminated above a brush barrier made of trees cut from the right-of-way and piled by the bulldozer before earthmoving began. Fills were built up of sidecast material and compacted only by repeated passes of the bulldozer. Roadbed grades were constant above each dip at 7% on Site 1 and 5% on Site 2. Separate measurements of soil loss were made for each of the three surfaces at a test site. Raised berms separated the roadbeds from the fills. Thus, all storm waters flowed off the outsloped and compacted roadbeds only at the dips. Strips of plastic film placed in the road margins near the dips inhibited erosion of the berms (Figure 1d). Berms permitted the measurement of erosion from fills independent of erosion caused by excess water flowing off the roadbed. Drop inlets collected stormflow from the dips, and metal troughs collected flows from the cut and fill slopes (Figure 1). Installations (Figure 1e) similar to those described by Douglass and Swift (1977) measured stormflows from each of the surfaces and collected sediment samples for each storm.

Total soil loss was the sum of two measurements. Dry weight of those heavier particles deposited in the collection troughs below the slopes and in the approach section ahead of each H-flume was determined from volume measurements and bulk density subsamples. Stormflows, carrying the lighter particles, were sampled by Coshocton wheels. Subsamples were filtered and sediment concentration determined by weight. The sediment concentration in ppm was multiplied by gauged stormflow to determine the total suspended sediment. The sum of deposited and suspended sediments was expressed as dry weight per unit area of the road or slope surface yielding the soil. Projected horizontal areas (map areas) were used in calculations for the four slope surfaces.

Precipitation was gauged by one recording and two nonrecording gauges, and the latter were read each time soil was collected. Precipitation totals were separated into 24-hour amounts.

Forest Service practice is to plant grass as soon as possible after earthmoving ends but this experiment was designed to compare soil losses from bare surfaces in several seasons so grass seeding was postponed for 9.5 months following road construction. In July 1977 after the timber sale was closed, all cut and fill slopes were fertilized, limed, and seeded to the standard roadside mixture of annual rye and Ky-31 fescue grass. Both roadbeds were graded and surfaced with 6 in. of crusher run gravel (Figure 1d). Measurements continued for an additional 13.3 months. Cumulative soil loss over the 22.8 months was partitioned into five time periods: the 2.5 months immediately after road construction (September through November 1976), the 4 winter months (December 1976 through April 2, 1977), the 3 spring months of 1977 when most of the logging traffic passed over the sites, the 5 summer and fall months after grass planting and graveling (July through November 1977), and the final 8.3 months to August 1978. Through the entire period of this study, weekly traffic on this road was at least 15 trips by lightweight cars, vans, or pickup trucks.

RESULTS

Cumulative soil losses for Sites 1 and 2 over each of the five periods are shown in Figure 2. Daily precipitation is given at the top of the figure. About 54% of the roadway was roadbed with the cut and fill slopes splitting equally the remaining 46% of disturbed surface. In contrast to Figure 2, the losses in Table 1 are weighted by the area percentage of each surface to the area of full roadway and converted to monthly rates. The sum for the three surfaces is the monthly mean loss for the entire roadway. Also listed in Table 1 are weighted mean losses for all the bare soil periods, the 13.3 months after graveling and seeding grass, and the entire study.

Postconstruction

Lower soil losses occurred in this initial period than during the winter or logging periods (Table 1), with the roadbed at Site 1 showing the greatest loss (Figure 2). During this period, roadbeds produced 46 to 66% of the total erosion from each site but in most of the later time periods, beds were the source of less than half the total soil loss. Loose soil material on the surface of new construction was especially vulnerable to movement by storms. More than half the soil loss on Site 1 occurred during the first storm, a 1.9-in. rain comprising only 14% of the rainfall total for the postconstruction period.

First Winter

The largest soil losses for all surfaces occurred during the first winter. Precipitation for January and February was below average but 13.74 in. in March 1977 makes this the fourth wettest March in the 50-year record at Coweeta. In 4 months the roadbeds yielded 42% of their 23-month cumulative soil loss, and the fill and cut slopes yielded 52 and 82%, respectively. The cut slopes had the greatest losses, primarily due to frost heaving and dry ravel. Beginning in December, diurnal freezing and thawing cycles loosened large amounts of

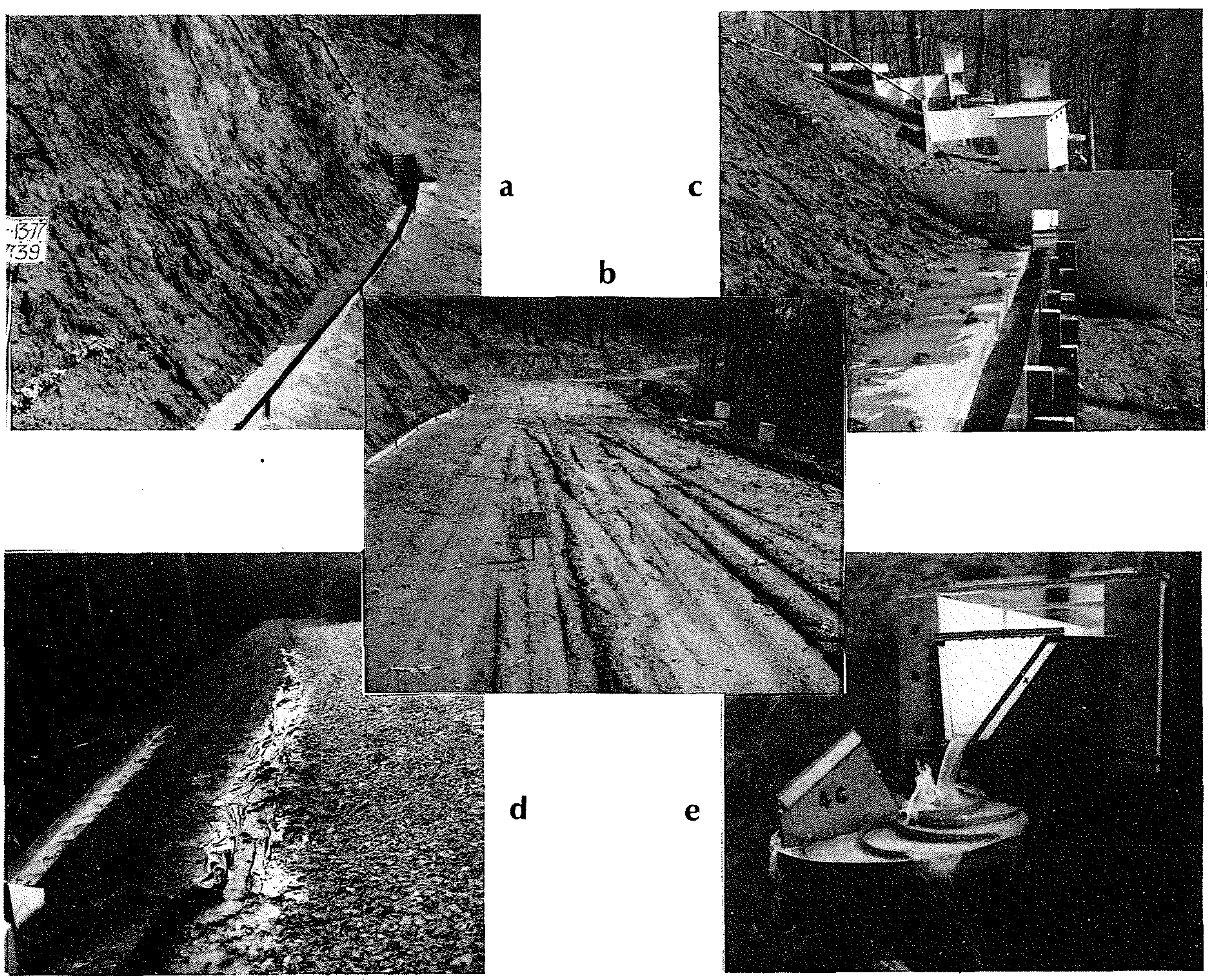

Figure 1. Instrumentation for soil loss measurements on roadbeds and cut and fill slopes at Coweeta Hydrologic Laboratory. (a) Bare cut slope, trough and drop inlet. (b) Bare soil roadbed in March 1977, facing downgrade toward the dip with cut slope trough on the left and berm on the right. (c) Bare fill slope, trough and headwall of flume. Sampling installations for roadbed and cut slope in the background. (d) View upslope from dip in September 1977 showing grassed fill and graveled roadbed with storm water running into drain inlet. (e) Typical 1-ft. H-flume and 2-ft. Coshocton wheel used to measure flow and extract 0.5% sample.

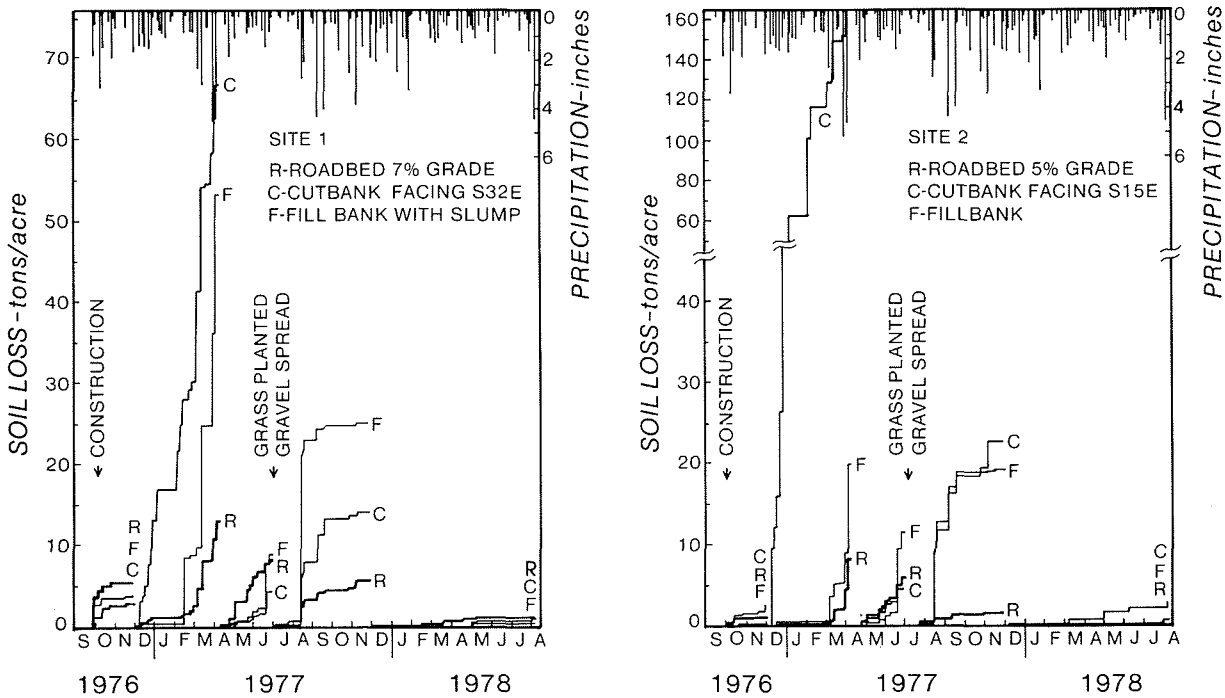

Figure 2. Cumulative soil loss and precipitation at two road sites on Coweeta Hydrologic Laboratory. Losses for cut slopes, roadbeds, and fill slopes are represented as weight per unit area for each surface.

Table 1. Mean monthly soil losses from three surfaces of a forest roadway at Coweeta Hydrologic Laboratory. Loss from each surface is weighted by proportion of that surface to total roadway area.

		Soil loss from surface			
Time period and site	Precipitation	Roadbed	Cut slope	Fill slope	Total roadway
	Inches/month	....	*Tons/acre/month*	....	
Postconstruction					
9/15/76–11/30/76	5.34				
1		1.18	0.27	0.34	1.79
2		.24	.25	.03	.52
Winter					
12/1/76–4/2/77	7.15				
1		1.77	4.31	3.04	9.12
2		1.13	11.19	1.22	13.54
Logging					
4/3/77–6/30/77	3.75				
1		1.48	.33	.68	2.49
2		1.10	.37	.80	2.27
New grass and gravel					
7/1/77–11/30/77	6.25				
1		.62	.64	1.15	2.41
2		.19	1.06	.91	2.16
Established grass					
12/1/77–8/8/78	4.88				
1		.08	.04	.01	.13
2		.01	.13	.02	.16
First 9.5 months					
9/15/76–6/30/77	5.66				
1		1.52	1.99	1.58	5.09
2		.89	4.89	.78	6.56
Last 13.3 months					
7/1/77–8/8/78	5.40				
1		.28	.26	.44	.98
2		.08	.48	.35	.91
Total 22.8 months					
9/15/76–8/8/78	5.51				
1		.80	.98	.91	2.69
2		.42	2.32	.53	3.27

soil material from the cuts and much of this debris tumbled into the collection troughs during non-storm periods (Figure 3a). Diseker and McGinnis (1967) blame frost action for high losses from Piedmont road cuts and found slope orientation and soil moisture to be useful predictors of loss. The yield from the cut slope on Site 2 (11.19 tons/acre/month) was more than double that from Site 1 (4.31 tons/acre/month). The apparent reason for less slope stability at Site 2 was its more southerly orientation which caused soil to dry and lose cohesiveness earlier and more often. This cut slope lost 9 times the amount yielded by the fill slope, or about 1 in. depth over the entire cut slope surface, an amount similar to that reported by Carr and Ballard (1980). If this were a road with an inside ditchline, the debris would have filled the ditch. Thus, the volumes measured here represent the load of material which would have been removed by maintenance or carried through a ditch and culvert by storm waters. Without a ditchline, debris at the toe of a cut slope normally stabilizes and soil losses offsite would be much less than these measurements suggest. In describing the ditchless road design developed at Coweeta, Yoho (1980) notes that "roadside ditches are man-made gullies and should be used only where needed."

While major soil losses from unvegetated cut slopes began with the onset of winter, the large losses from fills did not occur until early spring. Winter losses from both fill slopes were larger than roadbed losses, with the greatest loss at Site 1. Winter precipitation and snowmelt liquified a portion of this fill which slumped onto the edge of the collection trough in February (Figure 3c) and later was undercut by stormflows. Typically, new and uncompacted road fills in the southern Appalachian Mountains become wet and unstable in early spring and some slumps occur. Although losses are shown to continue (Figure 2), the slump of fill soil was a one-time event in this study. Without the collection trough, this soil material would have flowed onto the forest floor, lodged against a brush barrier at the toe of the fill slope, and caused minimum downslope disturbance. Haupt et al. (1963) reported heavy erosion of fills on an outsloped road and cutting was observed in some fills outside the test sites at Coweeta. Fill erosion was not the major factor in the test sites because storm water that normally would have been diverted over the soft fill by an outsloped roadbed and dip was, instead, confined on the roadbed and transported to the sampler for measurement.

Some rutting of roadbeds occurred during the spring thaw and both roadbeds washed in the larger March storms (Figure 1b). Less than 20% of the total loss from the roadway originated with the roadbed. In this and all other periods, Site 1 roadbed lost more soil than Site 2 roadbed. During the first winter, the 7% grade lost 57% more material than the 5% grade. Throughout the study, more than half of the roadbed collection was fine particles transported by water (suspended sediment) whereas less than 20% of the loss from fill and cut slopes was in this class. Material from the cut and fill slopes often fell or slid rather than being moved by water and consisted of all sizes of particles (Figure 3).

Logging Traffic

Losses from all surfaces were considerably less during the April to June period. Small storms and drier soils typical for this time of year counteracted the tendency for logging traffic to increase erosion from the roadbed. Logging traffic earlier in the spring did increase soil loss from nearby roads in a related study (Swift 1984). Road use in this period averaged 60 axle-counts per week. The fills were the most erosive surface on a per-unit area basis (Figure 2) with most soil lost in a 1.6-in. storm in June. However, on the weighted area basis, half the loss from the roadway came from the roadbeds (Table 1). Differences between sites were minor except that scattered clumps of volunteer grass developed on Site 1 fill and restrained some downslope soil movement.

New Grass and Gravel

Precipitation was negligible the first 45 days of the June-November 1977 period. Although slopes had been seeded 30 days earlier, grass had barely germinated before heavy rains (6.46 in. in 5 days) fell in mid-August. Slopes at both sites showed accelerated losses during this storm. The slumped fill on Site 1 and the cut slope on Site 2 again lost more soil than did the other surfaces, with the fill averaging 5 tons/acre/month. As expected (Swift 1984), roadbed losses were reduced by gravel and were notably lower for Site 2 where the grade was 5%. Soil loss from the 2 graveled roadbeds was observed to originate in the lightly graveled or bare margins (Figure 1d), and the difference between the low levels of loss from the two sites was associated with seemingly minor differences in area of exposed soil. At Site 2, gravel reduced average soil loss per month to about 20% of the rate for the first 9.5 months. By late September, the grass cover on the slopes of Site 1 was well-established and soil losses were greatly reduced; on Site 2, grass cover was less complete and increments of soil loss continued into early November.

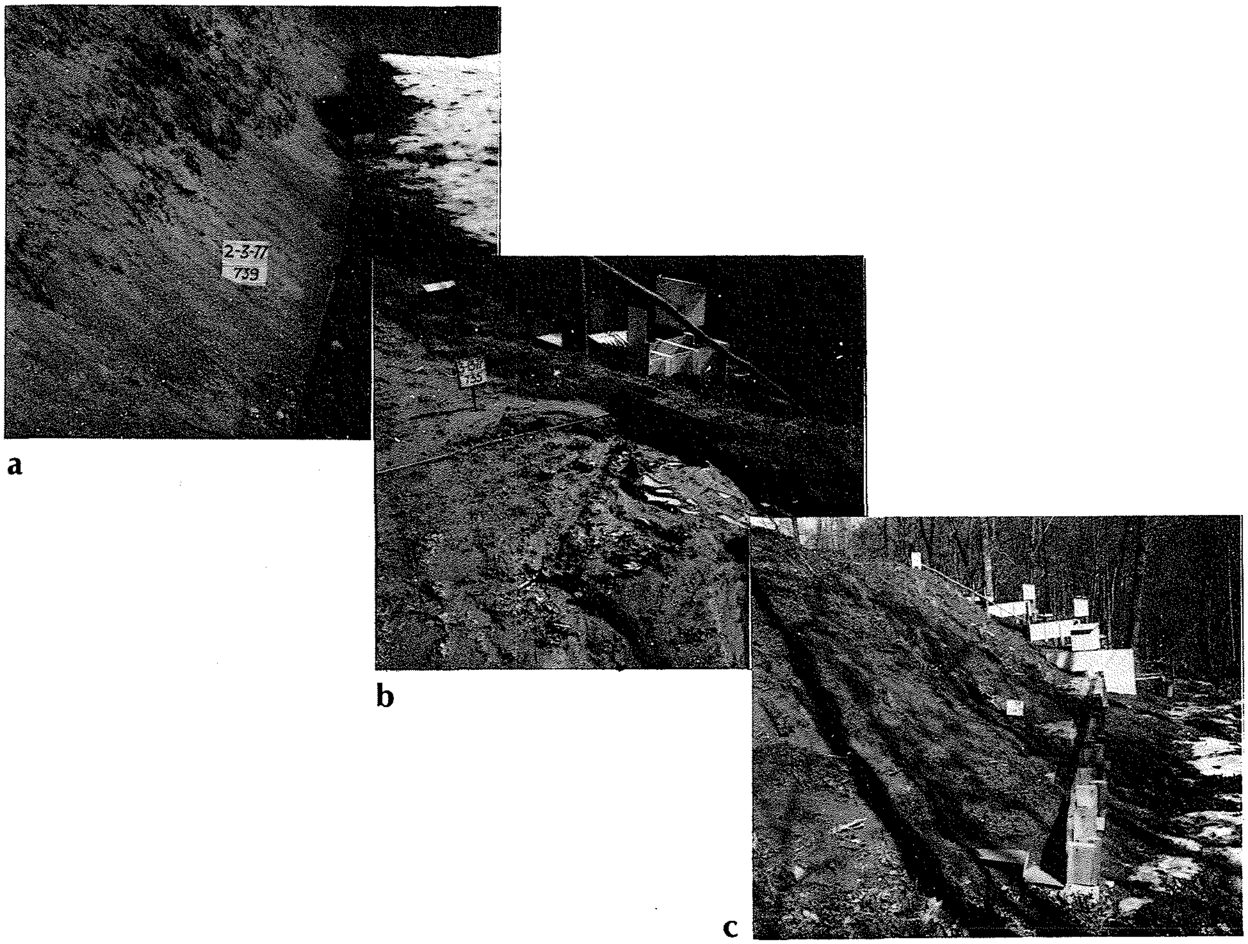

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Figure 3. Examples of three types of soil erosion measured on roadways. (a) Cut-slope trough filled by material loosened by soil frost. (b) Cutting of roadbed and deposition of waterborne soil particles near drain inlet. (c) Trough at Site 1 covered by new slump of fill on 14 February 1977.

Established Grass

Winter and early spring peaks of soil loss did not occur during the final period (December 1977 through August 1978) and total soil losses over 8.3 months were smaller than any previous period. The soil loss from each of the slopes and roadbeds was only 1 to 3% of the 23-month totals. The established grass protected the fill slopes and even wet season losses were negligible. The cut slopes did not undergo the loosening effect of soil freezing found during the first winter. Outside the study sites where grass was planted at construction time, only small amounts of debris had formed at the toes of cut slopes. The well-established grass cover seemed to prevent much of the frost action which loosened bare slopes. At Site 2, the thinner grass cover on the cut slope was sufficient to control soil loss during winter but inadequate to withstand four storms in spring and summer. Thus, the total soil loss for the final period was nearly 4 times the total for the other cut slope at Site 1. The roadbed with a 7% grade continued to have the greater loss rate. Grass growing in the margins of the roadbeds virtually eliminated the edge source of eroded material. Gravel with grass in the margins reduced average soil loss from both sites to less than 10% of the rate experienced in the 9.5 months before sites were graveled and grassed and to less than 5% of the rate in the first winter period. Even so, loss from the entire roadway was about 20 times the normal rate estimated for undisturbed forest by Patric (1976) or roughly half the acceptable rate for agricultural land.

IMPLICATIONS FOR MANAGEMENT

Two results are clearly demonstrated by this study. First, a key factor in erosion control for roads is surface protection. Second, the timing and causes of soil loss differ between cut slope, fill slope, and roadbed.

Surface Protection

- Without protection, heavy rains remove large amounts of soil from all portions of the roadway. If gravel is spread and grass cover established, soil losses are minor during large storms.
- Grass cover reduces winter loss of cut slope soils by reducing the frost heaving that promotes erosion.
- Grass cover restrains downslope movement of soil slumps in moistened fill slopes.
- Good gravel surface averts the soil loss and poor trafficability typical when bare soil roadbeds soften and rut in early spring.
- Grass on the entire roadway, except for the adequately graveled portion, should be planted and the cover maintained by reseeding or adding fertilizer and lime.

Time and Causes of Soil Loss

- Roadbeds generally encompass the largest portion of disturbed roadway area but accounted here for only 10 to 30% of the total soil loss. Soil loss from roadbeds was greatest during winter and the peak periods of logging traffic. The importance of keeping grades low was shown by consistently larger losses from the 2% steeper roadbed of Site 1.
- Cut and fill slopes produce the greatest soil losses. The highest losses come from cut slopes due to winter frost heaving. On many light-duty roads, losses can be reduced and soil held on site by using an outsloped roadbed design without an inside ditchline. Cut slope stability is enhanced if roadbed maintenance does not disturb debris at the toe of a slope.
- Temporary outer berms on outsloped roadbeds can reduce soil loss by keeping storm waters from flowing over erodible fills while grass cover is developing. Fills can be mechanically protected from erosion at broad-based dips. Fill slumps occur when soil reaches high moisture content, generally in late spring or during extended storm periods. Soil loss from fills can be reduced by using additional compaction, designs that avoid long fills, and brush barriers to restrain soil movement. Where fills can be kept away from waterways, the chances are reduced for soil erosion or slippage to directly enter streams.
- This road had a greater potential for soil loss than the original design described by Hewlett and Douglass (1968). Less soil was exposed with those narrower roads where cuts were vertical and shallow. Because less soil was moved, fills were smaller. Where the expected use does not require a wide roadbed and large-radius curves, a smaller road with lower erosion potential should be specified.

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